Quantity and Hydrologic Characteristics of Litter under Upland Oak Forests in Eastern Tennessee[1]

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ALTHOUGH LITTER is a major source of organic matter for forest soils and fundamental information on its classification, structure, and composition constitute an imposing volume of literature, we find that information is meager on the quantity and hydrologic characteristics of litter occurring under certain forest types and in certain regions. The Tennessee Valley Authority, in its program of forest development, timber production, and water control on the land, is concerned with what happens to the 50-inch rainfall each year on the 14 million acres of timberland in the Tennessee River Watershed. Accordingly, this study was made to determine the character of litter under the extensive upland oak forest in eastern Tennesee. This report presents estimates of total litter sampled under different stands at intervals of several years. Results for an upland oak stand include quantity of leaf fall as related to net accumulation during the year and the moisture-holding capacity of litter as related to occurrence of rainfall.

Review of Literature

Annual leaf fall reported for hardwood and mixed stands in eastern United States ranges from 2,400 to 3,100 pounds per acre (*10, 48*). For pine stands in Florida, Minnesota, and New York the range was from 1,700 to 3,500 pounds per acre (*2, 11, 21*). Mork (*39*) found that annual litter deposits in Norwegian timber stands varied from 700 to 3,000 pounds per acre. Coldwell and DeLong (*13*) show that average annual weights over a 3-year period for several species in mature Canadian stands ran from 1,500 to 3,000 pounds. Lunt (*34*) in Connecticut reports that annual needle fall was 21 percent greater for white pine than for red pine. Metz (*38*) states that in hardwood stands in South Carolina approximately 15 percent of the annual litter fall was twigs, bark, and fruit. Usually the annual fall of litter does not decompose completely in one year. This means an accumulation from year to year. The amount depends on forest type, soil type, and climatic conditions.

Sims (*48*) reported pine-oak litter accumulations of 3 to 4 tons per acre in North Carolina. Auten (*4*) found accumulations of 7 to 10 tons per acre in oak stands in the Central States region. Perry and Burrage (*44*) in studies of upland oak stands in eastern Tennessee, sampled at 5-year intervals, found litter varied from 6 to 8 tons per acre—with minor increase with lapse of years. Alway and Kittredge (*1*), sampling the forest floor under aspen-paper birch stands in the Lake Superior region, found that weights varied from 4 to 21 tons per acre. Stands of conifers in various sections of the United States show total litter weights varying from 3 to 27 tons per acre depending on species and age (*5, 7, 15, 28*).

Frank (*18*), Lull and Munns (*31*), and Munns (*40*) have pointed out the need for both additional knowledge and application of what we already know about the effects of management on soil and water conservation. Forest fires and grazing destroy the litter and humus that protect the soil surface. Loss of this soil mantle causes runoff, sheet erosion, and a decrease in the growth rate of trees. Perry and Coover (*43*) found a reduction of 60 to 70 percent in the volume growth of trees on frequently burned sites as contrasted with similar trees on protected sites, despite the wider crowns and more growing space on the burned areas. Rowe (*46*), in his studies in central California, reported surface runoff and erosion were markedly increased by annual burning. Rycroft (*47*) stated that autumnal burning in South African veld drastically increased volume of stream-flow and flood heights. Trimble, Hale, and Potter (*50*) found that livestock grazing in Allegheny woodlands reduced the organic content of the humus layer by 32 percent. Chandler (*9*) and Johnson (*26*) state that the grazing of farm woodlands results not only in the destruction of the forest tree reproduction, but also in a decreased growth rate and vigor of the trees due to deterioration of site. The annual removal of litter from woodlands for bedding of livestock, as practiced in European countries, can also prove harmful to tree growth (*41*).

Several investigators report significant differences in infiltration for soils covered with litter as compared with denuded, burned-over areas or erosion pavements (*3, 6, 25, 27, 29, 49*). Lowdermilk (*30*) states that forest litter is far more important for maintaining percolation capacity of soils than for absorption of rainfall. Meginnis (*36*) reported that during the flood of the Yazoo River in Mississippi, surface runoff from undisturbed forests was much less than from old fields.

Factors that aid in the decomposition of the forest litter are physical, chemical, and biological. Each one performs a definite function, but they are all integrated into the process of breaking down the organic matter into humus and topsoil. Physical properties such as species composition, temperature, and moisture strongly influence the manner and rate of decay (*17, 19, 20, 42*). Some chemical properties that provide for rapid decomposition are water-soluble organic mat-

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[1] Recognition is due J. S. Rothacher, formerly with TVA, and W. H. Cummings, formerly chief, TVA Forest Management Section, Forestry Investigations Branch, for their assistance in planning and conducting the study.

TABLE 1.—DESCRIPTION OF STANDS STUDIED ON NORRIS RESERVOIR BY MAJOR SPECIES, BASAL AREA, AND QUANTITY OF LITTER

Stand number and history	Major species by d.b.h. class					Basal area per acre, trees over 5.0" d.b.h.	Age of dominant stand	Period of study	Total litter during period	
	Less than 5.0"	5.0" to 11.0"		Over 11.0"					Start	End
	Species[1]	Species[1]	Basal area	Species[1]	Basal area				Weight per acre[2]	
			Percent		*Percent*	*Sq. ft.*	*Yrs.*	*Yrs.*	*Tons*	*Tons*
1. Heavy cut about 1933	Swd WO	Swd WO	13 9	ScO BO	27 13	41	78	2	4.5	4.2
2. Burned 1944	Dwd	ShP WO	7 7	BO ScO	49 14	77	68	5	2.2	11.5
3. Burned 1945	Dwd BW	ShP WO	12 4	BO Hick	40 12	94	85	4	3.5	11.8
4. Light improvement cut 1945	Dwd	ShP SRO	20 4	ShP BO	37 8	74	77	4	8.8	8.4
5. Light improvement cut 1945	YP WO	WO YP	13 5	WO Hick	50 13	61	85	4	4.4	8.5
6. Selectively-logged 1943	YP Dwd	YP Per	42 6	YP BO	31 7	50	37	5	8.9	4.2
7. Selectively-logged 1943	Dwd Swd	ShP BO	12 10	BO ScO	33 18	72	74	5	9.4	9.6

[1] Species abbreviations: BO, black oak; BW, black walnut; Dwd, dogwood; Hick, hickory; Per, persimmon; ScO, scarlet oak; Shp, shortleaf pine; Swd, sourwood; SRO, southern red oak; WO, white oak; YP, yellow-poplar.

[2] Total litter quantity based on field weights, except for stand 1 where weights are oven dry.

ter, percentage of nitrogen, acidity, and excess-base content; others, such as the lignin complex, waxy substances, resins, and hemi-cellulose content, slow up decomposition (*8, 13, 22, 37, 51*). Biological agents assisting in the decay of the forest floor include fungi, bacteria, earthworms, insects, and myriapods (*14, 16, 23, 35*). An example of the interaction of these agents is reported by Coile (*12*) who states that calcium aids decomposition through its reduction of acidity, which in turn has a profound effect on the microbial population that feed on organic matter.

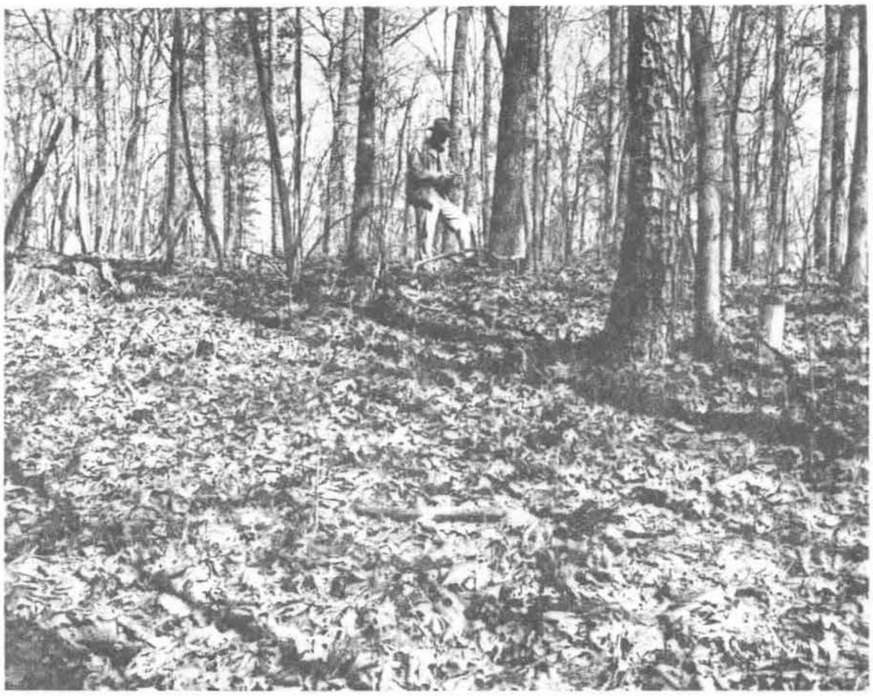

FIG. 1.—Stand 7, a typical selectively logged stand in eastern Tennessee where litter studies were conducted.

Description of Study Areas

This study deals with stands typical of east Tennessee. They represent fair to good upland forest sites on Clarksville and Fullerton cherty silt loam soils in the ridge and valley province of the Great East Tennessee Basin (Fig. 1). Essential information is given in Table 1 on the seven stands used in the litter study. These stands were also identified with other studies. Stand 1 is the sample acre of typical cut-over hardwoods used in the Clear Creek transpiration study established in 1948 (*45*). The other stands, Nos. 2-7, were used in a test established in 1945 and 1946 of nitrogen fertilizing following fire or cutting. However, the results on litter given here are only for the unfertilized or check plots in these stands. The history (Table 1) of these stands includes burning by wild fire that destroyed nearly all the forest floor, improvement cutting that removed weed species, and selective logging of overmature and defective trees. In composition, upland oaks are dominant in these stands except for shortleaf pine in Stand 4 and yellow-poplar in Stand 6 as indicated by major species in Table 1. These stands are uneven-aged with a light saw-timber volume, understocked with pre-sawtimber-size trees, and with dogwood prominent in the understory.

Study Procedures and Results

For the purpose of this study the term litter is that part of the forest floor including:

1. The L layer, or unaltered remains of plants and animals.
2. The F layer, consisting of partly decomposed organic matter.
3. That portion of the H layer that could be readily separated from the mineral soil with the fingers.

Large branches and other organic debris that would distort the sampling were excluded.

A uniformity trial to determine the size and number of samples of litter to give a standard measure for a predetermined percent of precision was made on 1.6 acres of plots in Stand 5, using three frame sizes: 1/100-, 1/10-, and 1/4-milacre, with 128 samples for each size. The 1/10 milacre sampling unit had the most stable coefficient of variation, so this size was selected for the sampling work. This trial showed that 40 sample units would give the weight of total litter on an acre with a standard error of 5 percent. Representative sampling was obtained by stratification, with four sample units randomly located on each tenth-acre.

The sampling technique was simple. Equipment included (1) a wood frame 2.08 feet square giving a 1/10-milacre sampling unit; (2) a set of screens—one coarse (½ in. hardware cloth) and one fine (No. 12 window screen), (3) a sharp, square-edged spade, (4) a light cardboard weighing box, and (5) household scales graduated in tenth pounds. The frame was laid on the litter and an exact area was outlined by cutting with the spade along the inside edge of the frame. The litter sample was then spread out on the coarse screen seated on top of the fine screen. Twigs over ¼ in. diameter and other coarse debris were picked out. After sorting, the balance of the coarse litter was transferred to the weighing box. Next, the contents of the fine screen were shaken to eliminate any mineral soil, and the remaining organic matter was added to the weighing box. Then the total litter sample was weighed, recorded and returned to the ground.

Total litter. — Total litter was measured in Stand 1 at bi-monthly periods from June 1948 to August 1950 to determine the increase by leaf fall and decrease by decomposition. Forty samples were collected every two months, the litter being returned to the ground after sample weights were recorded. Other small samples were taken nearby and oven-dried to determine the moisture content of litter at the time of sampling. This provided the basis for computing the dry weight of total litter on the acre. Figure 2 shows total litter accumulation and current leaf fall on the sample acre over the two years. Total litter weight varied significantly between sampling periods and follows a definite trend during the year with the exception of February 1949, which is considered erratic. The greatest accumulation averaged 5.5 tons per acre in December, which includes nearly the total leaf fall. During the early summer months the rate of decomposition is sufficient to decrease the average amount of litter to 4.2 tons per acre by August. The decrease from December to February suggests that there is some decomposition even during the late winter in this climate. The most stable measurements were those made in August. Apparently during this dry midsummer period leaf fall and decomposition are at a low ebb and nearly in balance.

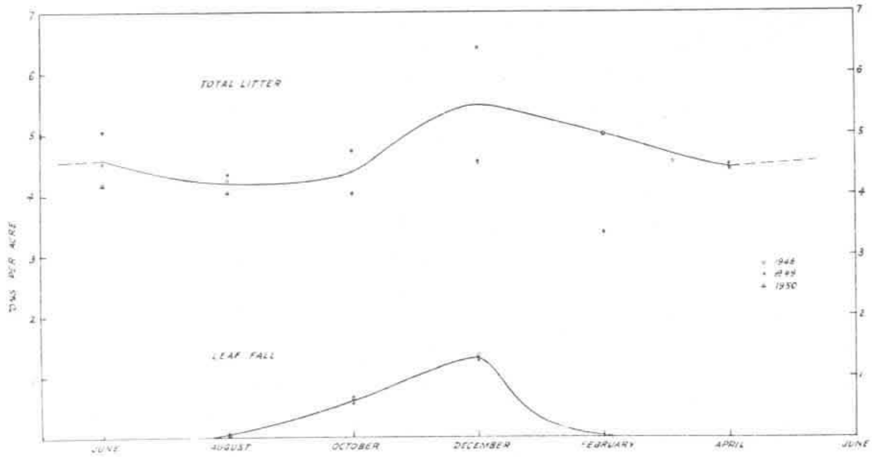

FIG. 2.—Weights of total litter and leaf fall for a two-year period under upland oak Stand 1 in eastern Tennessee.

Measurements of litter were taken on the fertilizer study plots (Stands 2-7) at time of establishment, after two years and at the end of five years. Random samples were collected in June when the litter was dry.

Table 1 lists the field weights of litter for the check plot in each stand at the start and at the end of the study. The variation in weight of litter was statistically significant, both for the three times of measurement and for the six stands. Of special interest is the rapid increase in litter weight following fire. In Stands 2 and 3, burned in 1944 and 1945, small quantities of litter remained. Average litter weight in these two stands increased from 2.8 tons to 11.6 tons per acre during the five-year period. In stands where light improvement cuts were made, the litter weight showed a definite increase in Stand 5, which is dominantly oak, but not in Stand 4 where shortleaf pine predominated in the overstory. In Stand 6, located in a cove, a heavy selective sawtimber cut in 1943 changed the cover type from mixed hardwood to nearly pure yellow-poplar. Here the distinct loss in field weight from 8.9 tons to 4.2 tons during the five years is attributed to a change in the character of the litter, that decomposes more rapidly than mixed oak litter. In Stand 7, located on a ridge, where only overmature and decadent trees were removed, there was a very slight (from 9.4 to 9.6 tons) increase in five years.

Current Litter.—Current litter,

chiefly leaf fall, and its rate of accumulation were measured in Stand 1 from August 1948 to April 1950. Forty screens, each 6 square feet in area, were placed on the ground to catch the leaf fall. Later the screens were covered with burlap to prevent fallen leaves from skidding off. Leaves of the 1948 crop were collected from the screens in August, October, December, February, and April and separated by species. Samples of leaves of the major species were oven-dried to determine the total weight. Small twigs and acorns passing ½-inch screen were also included in total current litter weight.

The amount of current leaf fall follows a pattern normally expected in a hardwood stand (Fig. 2). A small quantity, 0.05 ton per acre, falls in August. By October, another 0.55 ton has fallen, by December another 0.70 ton. The measured total annual leaf fall averaged 1.3 tons per acre for the two seasons.

The average annual leaf fall is reflected in the curve (Fig. 2) showing the accumulation of total litter. As leaf fall progresses during the fall months, the weight of the litter on the ground builds up to average 5.5 tons. Actually both curves would be expected to reach a peak in early November when the leaf fall is nearly complete, although this is not shown by the data collected. The average weight of foliage on the same sample acre obtained by estimating the foliage is summarized in another report[2] as follows:

Month and year	Foliage on trees Pounds per acre o.d.w.
1948	
June	2,630
August	3,100
October	3,200
1949	
June	3,170
August	3,340
October	2,800

The June sampling for the two years showed an average foliage weight of 1.4 tons per acre, August 1.6, and October 1.5. This variation during the growing season is due to leaf development and leaf fall. The total number of leaves at time of sampling, as estimated by regression equations, averaged 9 million per acre.[2] Foliage on all trees greater than 0.5 inch d.b.h. averaged 1.5 tons (oven-dry) for the 2-year sampling on Stand 1.

Table 2 shows the quantity of foliage and progress of leaf fall by major species. The understory species of sourwood, black gum, and dogwood lose their leaves earlier than the overstory species. For the two seasons of the study an average of 4 percent of the leaves fell by late August, an additional 42 percent by mid-October, and the balance of 54 percent by early December. This accounts for all major leaf fall except for an estimated 10 percent of white oak leaves and a minor amount of post oak leaves which persist until April.

Moisture Content of Litter.—Moisture content of litter was sampled in Stand 1 at various times during 1948 and 1949, during dry and wet periods, also at different times during the day. Field moisture content was determined on all 66 samples by oven drying to a constant weight at 100°C. Water-holding capacity was determined for 60 samples. These were soaked in water for 90 minutes, allowed to drain 30 minutes, then reweighed, and finally oven-dried to a constant weight at 100°C.

Moisture content of litter was analyzed in relation to relative humidity, amount of rainfall, and number of days since the last rain of 0.25 inch or more. The amount of rainfall and relative humidity showed only insignificant influence. However, number of days since last rain gave a highly significant correlation with litter moisture content. This relation was described by the regression equation: Log of moisture percent $= 2.1278 - 0.5125$ log of days since last rain. It is presented as a curve in Figure 3 for the estimation of moisture content of litter. One day after a rain all excess water is apparently lost and the moisture content of the litter stands at field capacity, amounting to 135 percent. Moisture loss progresses at a rapid rate to approximately 41 percent after ten rainless days. Then it continues, but at a much slower rate, down to a minimum moisture content of about 20 percent, with slight diurnal variation due to relative humidity. Litter samples collected a short time after isolated storms contained as high as 150 to 175 percent moisture, which accounts for the temporary detention storage that occurs immediately after a major rain. This range is indicated in Figure 3 as the broken portion of a curve above indicated field capacity.

The moisture content of the series of samples saturated in the laboratory ranged from 200 to 250 percent of the oven-dry weight. This saturated condition represents the maximum water-holding capacity for the litter in contrast to the field capacity of 135 percent.

TABLE 2.—QUANTITY OF FOLIAGE ON TREES AND PROGRESS OF LEAF FALL FOR 1948 CROP OF LEAVES BY MAJOR SPECIES ON THE ONE-ACRE TRANSPIRATION STUDY (STAND 1)

Species	1948 foliage on trees			1949 foliage on trees			Leaf fall in percent for 1948 crop		
	June	August	October	June	August	October	August	October	December
	Pounds o.d.			*Pounds o.d.*			*Percent*		
White oak	370	440	420	700	650	350	0	16	74[1]
Black oak	400	460	530	320	520	330	0	3	97
Scarlet oak	570	870	780	850	760	800	1	12	87
Chestnut oak	90	100	100	70	130	120	0	4	96
S. red oak	160	240	160	230	190	200	0	43	57
Post oak	40	30	60	—[2]	40	—[2]	0	71	29
Hickory	130	—[2]	180	100	190	90	0	52	48
Sourwood	260	310	—[2]	310	360	330	1	99	0
Blackgum	70	70	—[2]	90	90	70	63	37	0
Dogwood	80	90	—[2]	70	70	100	3	72	25
Red maple	40	30	—[2]	—[2]	30	—[2]	0	32	68
Shortleaf pine	290	190	370	250	210	240	0	20	80

[1] Of the remaining 10 percent, one-half was lost by February and the remaining half by April.

[2] Not sampled.

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[2] Rothacher, Jack S., Frank E. Blow, and Sara M. Potts. Estimating the quantity of tree foliage in oak stands in the Tennessee Valley. JOUR. FORESTRY 52: 169-173. 1954.

Discussion

The average annual leaf fall of 2,600 pounds per acre found in a mixed oak stand (No. 1) in eastern Tennessee compares with the 2,400 to 3,000 pound range reported by Sims (*48*) for a pine oak mixture in North Carolina and by Chandler (*10*) for second-growth hardwood stands in New York. The range from 2 to 12 tons of total litter per acre found in this and other stands in eastern Tennessee is attributed to stand history. The expected build-up of litter in burned stands indicates a considerable period of time is needed before the litter accumulation reaches the point of equilibrium recognized in other investigations (*24*).

The average amount of precipitation held by the litter under field conditions amounts to approximately 135 percent of its oven-dry weight. This amount caught, held, and evaporated after each isolated storm is equivalent to 0.05 inch of rain. It is conservatively estimated that the litter intercepts and returns to the atmosphere 1 inch of rainfall annually in this area where the total averaged 52 inches for the past five years. However, the value of the litter layer in retarding evaporation from the soil surface outweighs this minor amount of precipitation that does not reach the soil. Moreover, the litter retains some excess water after a heavy rain, serves as a temporary reservoir, and also maintains soil conditions more favorable to infiltration. On trenched plots of another study in this stand it was found that the upper 4-inch soil layer of bare ground was 20 percent drier than litter-covered soil.

Lowdermilk (*30*) reported an average maximum water-holding capacity of 180 percent on an air-dry basis in pine-fir litter in California. In the oak forests of eastern Tennessee the maximum water-holding capacity on an oven-dry basis averaged 225 percent. Using an average of 35 percent moisture on air-dry litter, then the average water-holding capacity of oak litter on an air-dry basis would be 190 percent.

The correlation of the number of days since a rain of 0.25 inch or more with the amount of moisture in litter has direct application for determining indexes of forest fire danger in upland oak forests in eastern Tennessee. The steepness of the curve (Fig. 3) for the first few days after a rain indicates the rapid moisture loss by evaporation during that period. After about twenty days further moisture loss from the litter is relatively minor. Beyond this point, it is possible that variation in relative humidity can become an important determinant in fire danger.

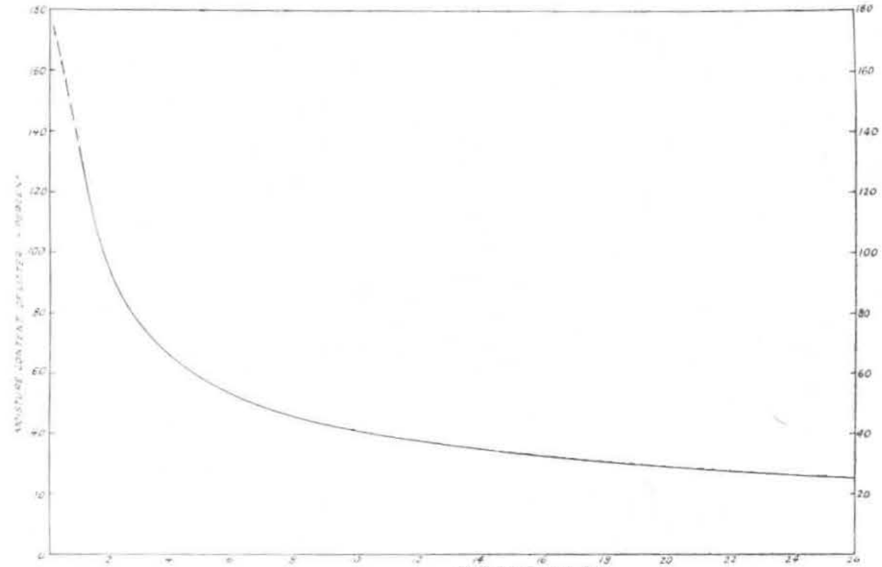

FIG. 3.—Average moisture of litter based upon 66 observations under upland oak Stand 1 in eastern Tennessee.

Removal of the litter by burning, or otherwise, destroys this absorptive layer. Rainfall then strikes the soil directly which results in excessive run-off. Recent experience in the fall of 1952 in east Tennessee has shown that the entire litter layer can be consumed by fire on extensive areas, thus resulting in extreme soil exposure. Although this litter can be replaced gradually by leaf fall, permanent damage may have been done to the site.

The nutrient content of leaf litter has been reported by several workers in this field (*2, 10, 11, 32, 33, 38, 39*). In general, it seems that hardwood litter contains more of the essential elements than coniferous litter. Metz (*38*) proposes that understory species such as dogwood and redbud are desirable in pine stands. The higher calcium content of these leaves would assist in faster decomposition of pine needles. Others contend that decomposition is more rapid in mixed stands due to the same effects. These nutrients, contained in more than a ton of hardwood litter deposited each year, should be of great value in maintaining site quality.

Prudent management of hardwood forests involves more than production of stem-wood. Maintaining normal leaf fall and litter accumulation is also an important function of site management. Practices that retain the litter layer and preserve the physical, chemical, and biological factors that control decomposition aid in maintaining maximum site quality.

Summary

The quantity of litter found in several upland oak stands in eastern Tennessee ranged from 2 to 12 tons per acre. Fire, cutting practices and stand composition are factors that cause variations in the litter layer. On one mixed oak stand annual leaf fall added an average of 1.3 tons of litter to the forest floor. Total litter reached a peak of 5.4 tons in December following leaf fall and then decreased to a fairly stable low August weight of 4.2 tons.

The moisture content of hardwood litter, at field capacity, was found to average 135 percent of its oven-dry weight. Temporary detention of additional moisture immediately after a rain increased the amount up to 175 percent. Complete saturation of the litter in the laboratory gave moisture contents up to 250 percent. The normal moisture content of the litter depends primarily on the number of days since the last rain of 0.25 inch or more. Moisture content decreases rapidly to 41 percent after 10 days and then gradually to 25 percent at 20 days. Here it becomes relatively stable subject to minor fluctuations due to relative humidity.

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